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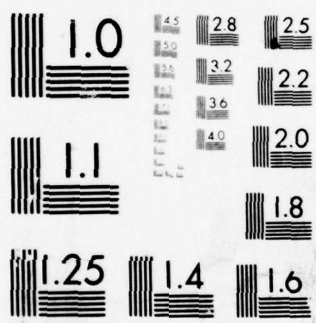

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NWC Technical Memorandum 2527

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PROJECT FOGGY CLOUD VII—WARM FOG DISPERSAL AND PREVENTION (PRELIMINARY SUMMARY)

by

Roger F. Reinking

Earth and Planetary Sciences Division
Research Department

NAVAL WEAPONS CENTER
China Lake, California 93555 • April 1975

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FOREWORD

This report has been prepared for timely presentation of information on Project Foggy Cloud VII and associated balloon research which began in July 1974 and will be completed at the end of the fiscal year. This report precedes final data analyses, so conclusions are subject to revision. It is released at the working level.

Project Foggy Cloud is supported by the Naval Air Systems Command under Air Task A370-05F0/216C/IW3712-0000. The balloon research is supported by the Office of Naval Research under Task R033-03-01.

NWS, NAS Lemoore, provided fog forecasting services and on-site weather observers for field operations. Project rawinsonde/GMD operators were from NWS, NAS San Diego. Air controllers for project operations were provided by NAF, China Lake. Mr. Chuck Lee, Manager of Visalia Municipal Airport, California, is acknowledged for his full cooperation and assistance in arranging for use of the airport grounds for the field site.

PIERRE ST.-AMAND
Head, Earth and Planetary Sciences Division
Research Department
17 April 1975

NWC TM 2527, published by Code 602,
April 1975, 30 copies.

(18) GIDEP

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GOVERNMENT-INDUSTRY DATA EXCHANGE PROGRAM

GENERAL DOCUMENT SUMMARY SHEET

Please Type All Information – See Instructions on Reverse

1. ACCESS NUMBER (19) E096-0747	2. COMPONENT/PART NAME PER GIDEP SUBJECT THESAURUS General Technical Data, Environmental Studies	
3. APPLICATION Weather Modification	4. MFR NOTIFICATION ☐ NOTIFIED ☒ NOT APPLICABLE	5. DOCUMENT ISSUE (Month/Year) April 1975
6. ORIGINATOR'S DOCUMENT TITLE (6) Project Foggy Cloud VII, Warm Fog Dispersal & Prevention (Preliminary Summary) (11)		7. DOCUMENT TYPE ☒ GEN RPT ☐ NONSTD PART ☐ SPEC
8. ORIGINATOR'S DOCUMENT NUMBER (14) NWC-TM-2527 2nd	9. ORIGINATOR'S PART NAME/IDENTIFICATION N/A	(12) 35p.
10. DOCUMENT (SUPERSEDES) ([redacted]) ACCESS NO. E076-0565	11. ENVIRONMENTAL EXPOSURE CODES N/A	
12. MANUFACTURER N/A	13. MANUFACTURER PART NUMBER N/A	14. INDUSTRY/GOVERNMENT STANDARD NUMBER N/A

15. OUTLINE, TABLE OF CONTENTS, SUMMARY, OR EQUIVALENT DESCRIPTION

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A new airborne charged spray system for warm fog dispersal was developed during the project. Initial tests provided positive results. Complete field testing of the system will be undertaken during the next suitable fog season.

An ion generator for inducing fog droplet coalescence was built and tested in the field. The data show that the scale of the treatment must be larger to provide the experimental control needed to obtain conclusive results. Alternatively, this technique should be tried in a large-volume cloud chamber.

Meteorological data were collected to evaluate a concept of establishing a stratus cloud layer to inhibit formation of fog. The technique that would be applied involves seeding clear air with hygroscopic particles to produce stratus droplets which cause a trapping of earth-atmosphere radiation. The seeding technique is practical and the meteorological potential was shown to be substantial.

Much other basic physical and microphysical information on fog processes relevant to fog modification and forecasting was gained with an instrumented, manned hot-air balloon and a comprehensive ground-based instrument system.

(10) Roger F./Reinking

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16. KEY WORDS FOR INDEXING Weather Modification; Fog Disposal; Charged Spray System; Ion Generator; Meteorological Data; Seeding Air; Hygroscopic Materials; Hot-Air Balloon (Doc Des--P)

17. GIDEP REPRESENTATIVE M. H. Sloan	18. PARTICIPANT ACTIVITY AND CODE Naval Weapons Center, China Lake (X7)

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ABSTRACT

This paper is a preliminary summary of progress made during Project Foggy Cloud VII.

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An ion generator for inducing fog droplet coalescence was built and tested in the field. The data show that the scale of the treatment must be larger to provide the experimental control needed to obtain conclusive results. Alternatively, this technique should be tried in a large-volume cloud chamber.

Meteorological data were collected to evaluate a concept of establishing a stratus cloud layer to inhibit formation of fog. The technique that would be applied involves seeding clear air with hygroscopic particles to produce stratus droplets which cause a trapping of earth-atmosphere radiation. The seeding technique is practical and the meteorological potential was shown to be substantial.

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INTRODUCTION

Fog-related ship and aircraft accidents have cost the U.S. Navy 74 lives and 113 million dollars over the past five years. Nationwide, in the civilian sector, the annual expense due to fog-related highway accidents reaches 300 million dollars, in addition to the more tragic losses of life.[1] These occurrences clearly explain why the Navy and many other agencies are interested in fog research and fog dispersal. Emphasis is primarily, but no exclusively, on warm fog.

The Project Foggy Cloud series of experiments represents the effort of the Naval Weapons Center (NWC) in warm fog investigations. Foggy Cloud is supported by the Naval Air Systems Command. The central objective of the Foggy Cloud exploratory research is to develop efficient methods of dispersing and preventing warm fog. The methods sought will enhance or trigger natural processes with minimum expenditures of materials and energy.

Project Foggy Cloud VII is nearing completion. The principal effort in this project was centered on improving NWC's airborne system for increasing visibility by spraying fogs with electrostatically-charged water droplets. This work began with FY 1975 and included laboratory testing, designing, and field testing. The field study phase was initiated on 18 November 1974 and continued until 15 February 1975. The primary tests in the field project were designed to assess the utility of the electrostatic system. The field experiment phase also included tests of a fog-dispersing ion generator and preliminary experiments to test the feasibility of substituting a low stratus cloud for fog so as to keep the first few hundred feet of air clear. Finally, the project included physical studies of the fog using an instrumented hot-air balloon and ground-based instrumentation.

The object of this paper is to present an overview of this project, with a preliminary summary of progress and plans for future work.

[1]Wheeler, S.E., "Marine Fog Impact on Naval Operations," MS Thesis, Naval Postgraduate School, Monterey, Calif., 1974. 118 pp. (NPS-58WH74091.)

FIELD TEST SITE

The field test facility for Foggy Cloud VII was constructed at Visalia Municipal Airport in the San Joaquin Valley. This is a change from previous Foggy Cloud experiments, most of which have been based on the northern coast of California, at the Arcata-Eureka Airport. A schematic of the Visalia site is shown in Figure 1.

The earliest opportunity for testing the new electrostatic fog dispersal system corresponded to the winter San Joaquin Valley fogs. These warm, radiation fogs form under calm conditions. Therefore, these fogs are more easily treated for dispersal and observed for effects than rapidly advecting and mixing coastal fogs. This is a definite advantage in the experimental stages of testing. Figure 2 illustrates the calm conditions during a case study at Visalia.

Fog records at NAS Lemoore, which is near Visalia, reveal an annual average of 325 hours with ceilings below 200-ft AGL and visibilities under 1/2-mile during the November-February fog season (Figure 3). A normal season can provide ample testing time.

Fog studies in the San Joaquin Valley directly benefit DOD airports in the valley, numerous civilian airports, and the Valley highway and railway systems, all of which continue to suffer substantial accident time and dollar losses. The results may be extrapolated to marine fogs.

THE ELECTROSTATIC FOG DISPERSAL SYSTEM

Charged droplets greatly increase the efficiencies of the collision-coalescence process. Charged spray droplets induce dipoles in neighboring fog droplets. This leads to electrostatic attraction, enhanced growth by collection, and fallout. An electrostatically-induced shift in the fog droplet size distribution toward larger sizes will in itself result in increased visibility by reducing scattered light. The induced precipitation will result in further clearing.

Project Foggy Cloud VI, which was conducted at the Arcata-Eureka Airport, provided field testing of a prototype airborne fog-dispersal system which sprayed water and charged the spray by induction. The system was mounted on a B-26 aircraft as shown in Figures 4-6. The major advances from the testing were made in defining the engineering requirements for operating a spray-charging system in fog. Excessive leakage currents had to be reduced, greater charging currents had to be achieved, and a greater volume-flow of spray was needed. Among the main problems were arcing from the spray boom to the grid and leakage currents caused by water flowing from the metal spray boom across insulators to the nozzles. Also, shielding of the inner stream of spray from each nozzle

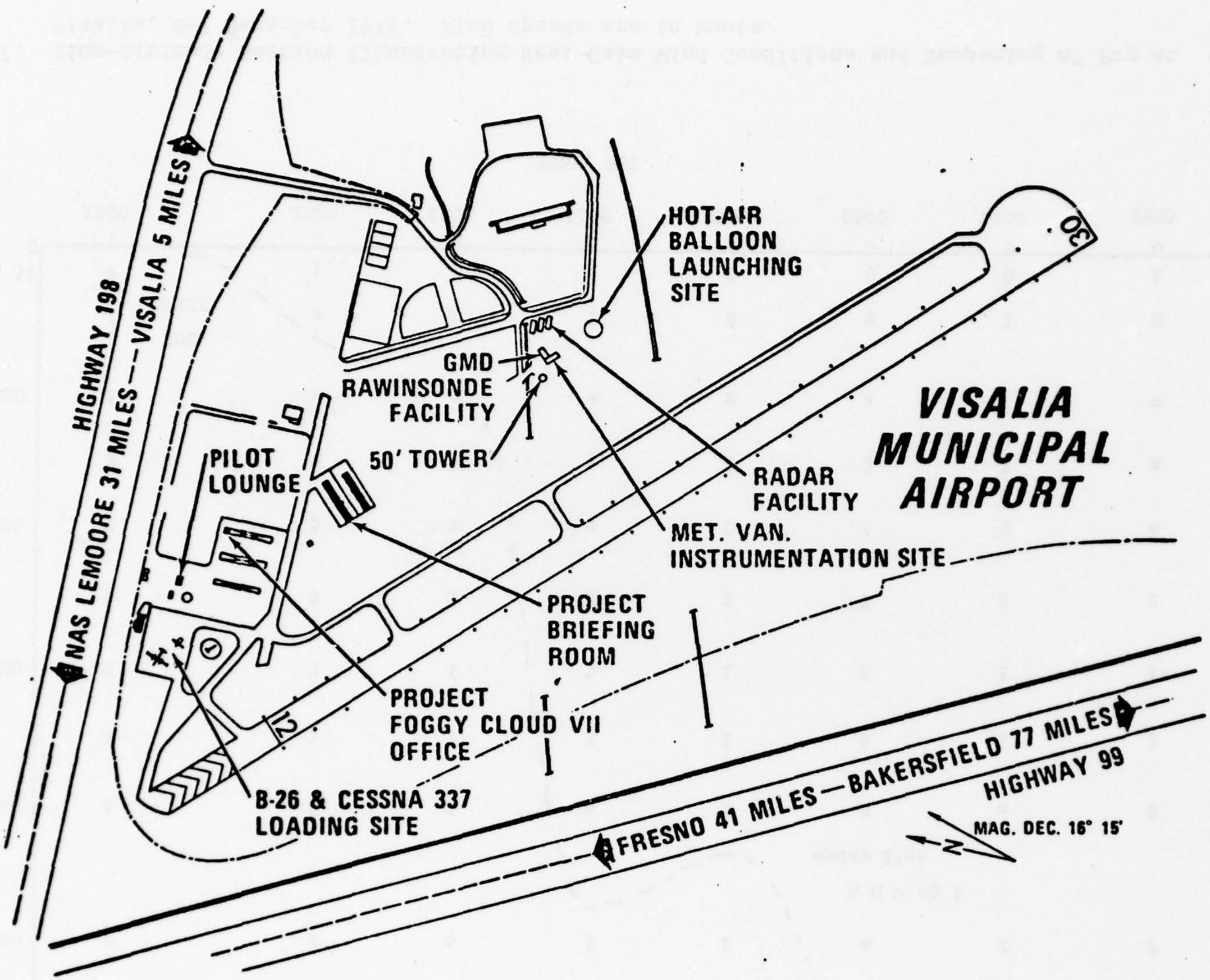

FIGURE 1. Schematic of Project Foggy Cloud VII Field Site at the Visalia, California, Municipal Airport in the San Joaquin Valley.

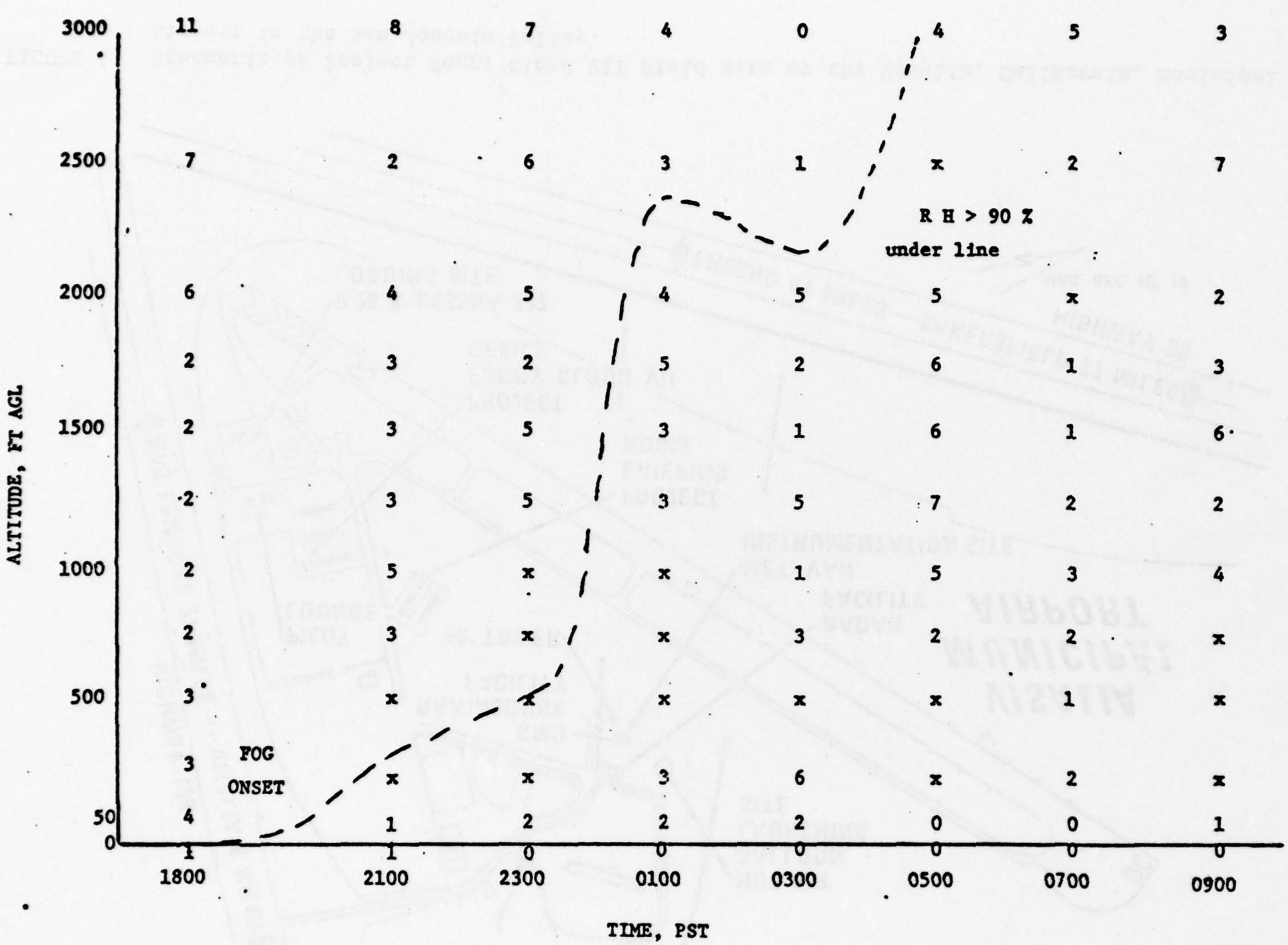

FIGURE 2. Time-Altitude Section Illustrating Near-Calm Wind Conditions and Deepening of Fog at Visalia, 6-7 December 1974. Wind Speeds are in knots.

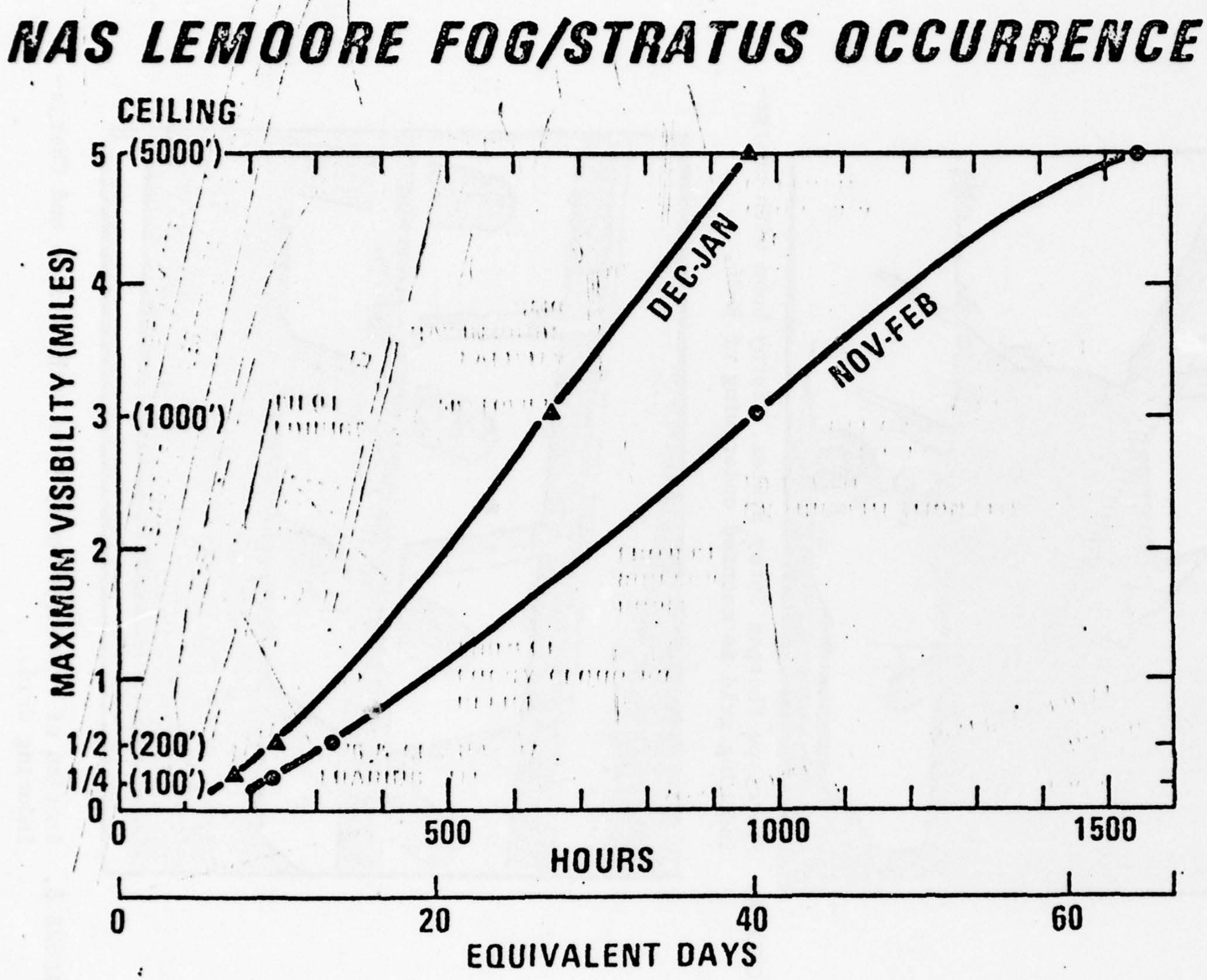

FIGURE 3. Climatological Occurrence of Low Visibilities at NAS Lemoore.

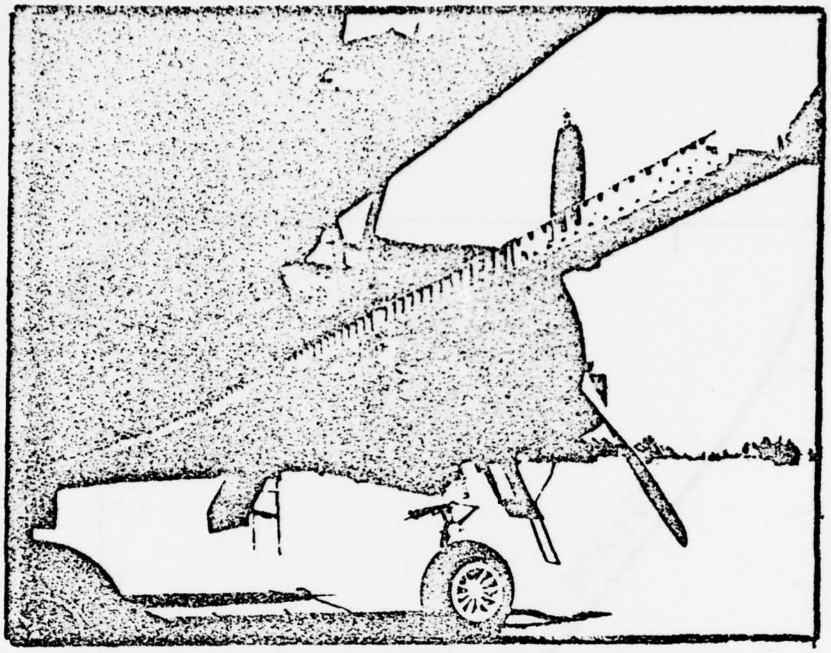

FIGURE 4. Prototype Charged Spray System. Spray boom with charge-inducing grid is mounted under wing of B-26.

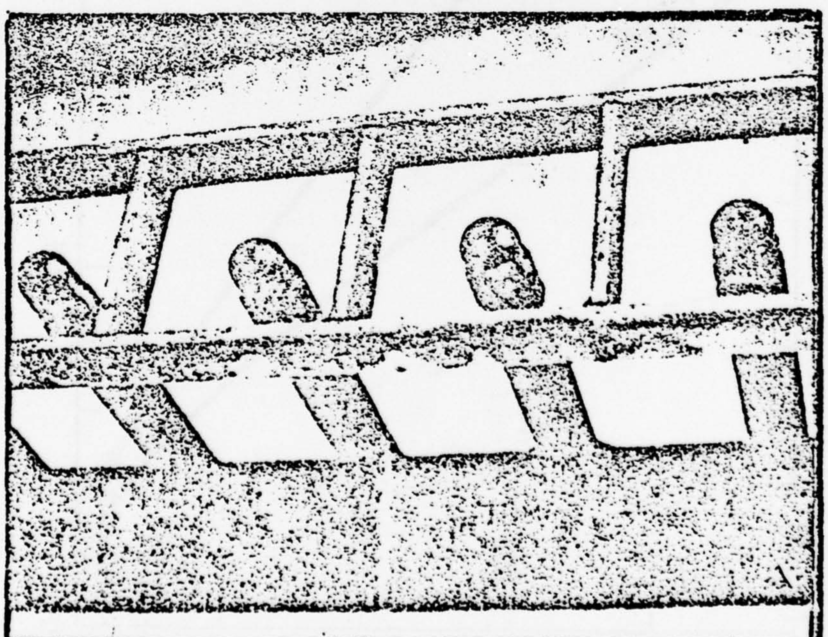

FIGURE 5. Section of Prototype Spray Boom With Nozzles and Charge-Inducing Grid.

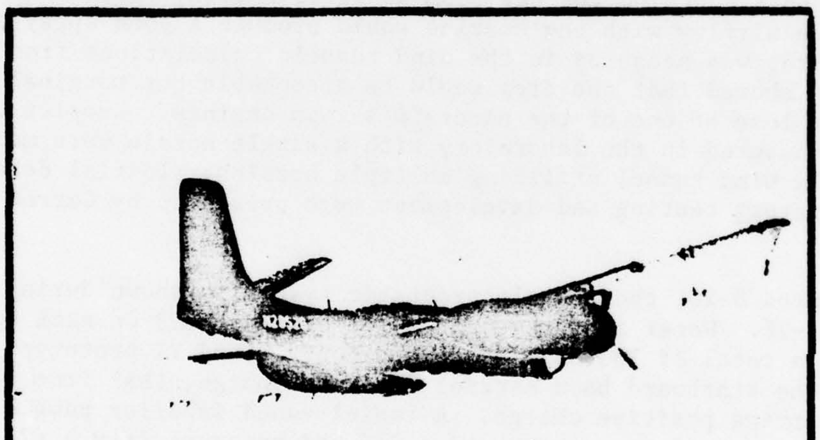

FIGURE 6. Flight Test of Prototype Electrostatic System. Low-volume spray from boom is not visible.

by the outer portions may have reduced the level of charging achieved.

The design, laboratory testing, and fabrication of a new induction-charging spray system was undertaken in July of 1974. In the laboratory, interrelationships of fluid flow-rate, spray drop-size distribution, and charging efficiency were determined for various combinations of spray nozzles, fluid pressures, and induction ring configurations. Droplets with charges as high as 0.26 of the Rayleigh limit were obtained; this achievment demonstrated that large concentrations of spray drops with sufficient charge to cause increases in visibilities in fog can be generated in a practical manner. A wind-tunnel test section of the new spray boom is shown in Figure 7. Wind tunnel tests demonstrated that airflow around and behind the new boom would be smooth, and that interaction of the airflow with the nozzles would produce a good spray pattern. The drag was measured in the wind tunnel; calculations from the measurements showed that the drag would be acceptable but marginal in the event of loss of one of the aircraft's twin engines. Droplet charging levels measured in the laboratory with a single nozzle were maintained in the wind tunnel utilizing multiple nozzles. Initial details of the laboratory testing and development were presented by Carroz and Keller.[2]

In Figures 8-10, the new electrostatic system is shown during mounting on the B-26. Water is sprayed from 786 nozzles, 393 on each boom, compared to a total of 133 nozzles on the Foggy Cloud VI prototype. The spray from the starboard boom carries negative charge, that from the port boom carries positive charge. A radial-vaned impeller pump driven by a Corvair engine forces water under 300 psi pressure from a 675-gallon tank into the spray booms at a rate of 55 gallons per minute. Flight tests were conducted at China Lake and Visalia. The system was proven airworthy. The capability of producing a heavy spray was demonstrated (Figures 11 and 12). Sprays from the two booms were carried in the aircraft vortices and remained separate and distinct as far as three miles behind the aircraft (Figure 11). Thus, when the aircraft is flying along straight paths, there is no need for concern over the possibility that the oppositely-charged sprays will merge and neutralize the droplets prior to interacting with the fog.

Measurements of the atmospheric electric field produced by the charged spray system were made by flying passes at several altitudes over the Visalia instrument site. Significant increases in the electric field near the ground were induced by passes at all selected flight altitudes (100-700-ft AGL). The increases above the fair weather field ranged from

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[2]Carroz, J. W., and P. Keller, "Laboratory Studies of Induction Charging for the Development of a Warm Fog Clearing System," presented at 3rd Annual Conf. on the Physics of Marine Fogs, 7-8 January 1975, Naval Electronics Laboratory Center, San Diego, California, 1975.

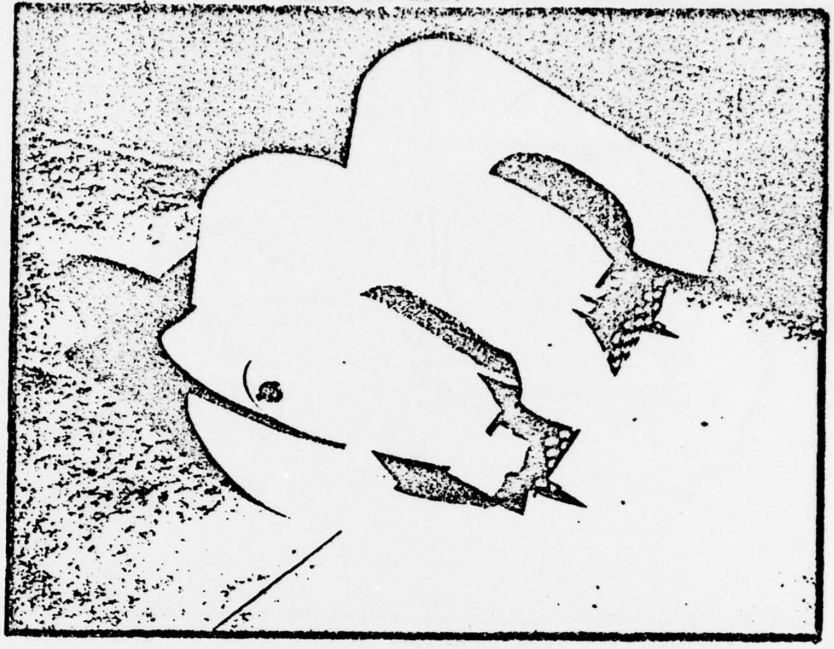

FIGURE 7. Wind Tunnel Test-Section of New Fiberglas Boom. Water is pumped to nozzles through main pipe within airfoil. Aluminum induction grid, with a ring centered on each nozzle, is supported and electrically insulated by vertical fiberglas pylons.

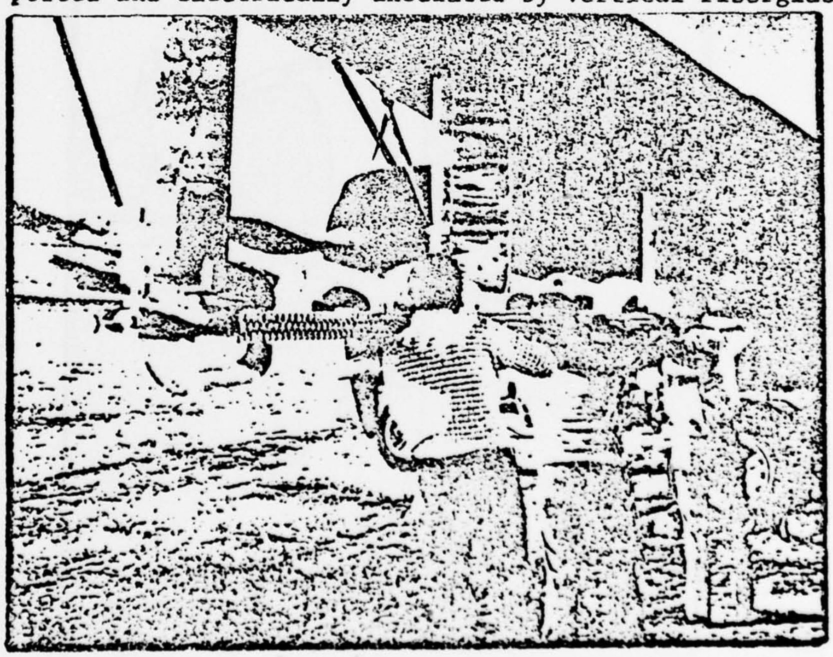

FIGURE 8. Mounting the New Electrostatic Fog Dispersal System and Adjusting Spray Nozzles.

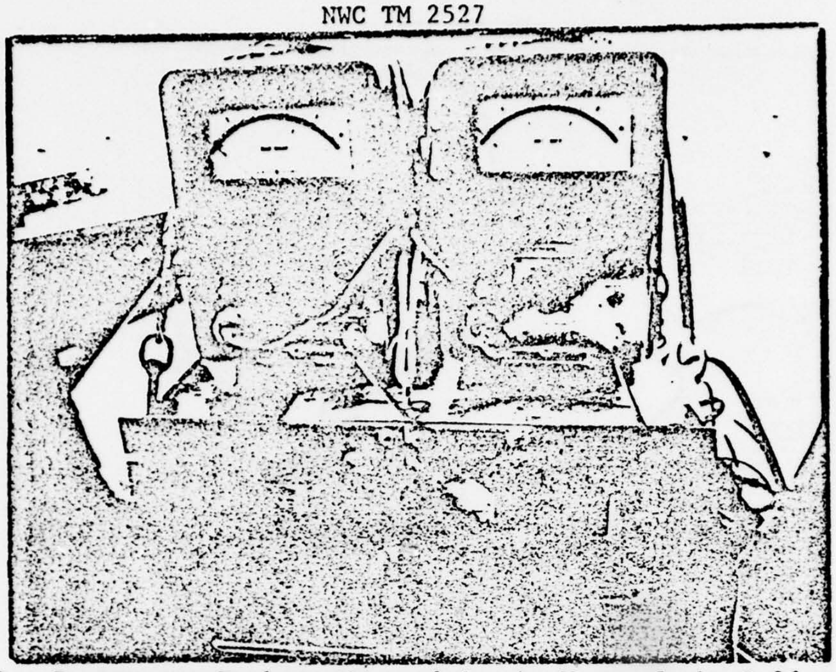

FIGURE 9. Instrument Package Mounted in the Nose of the B-26. This was used to monitor voltages and the charging and leakage currents in the spray system.

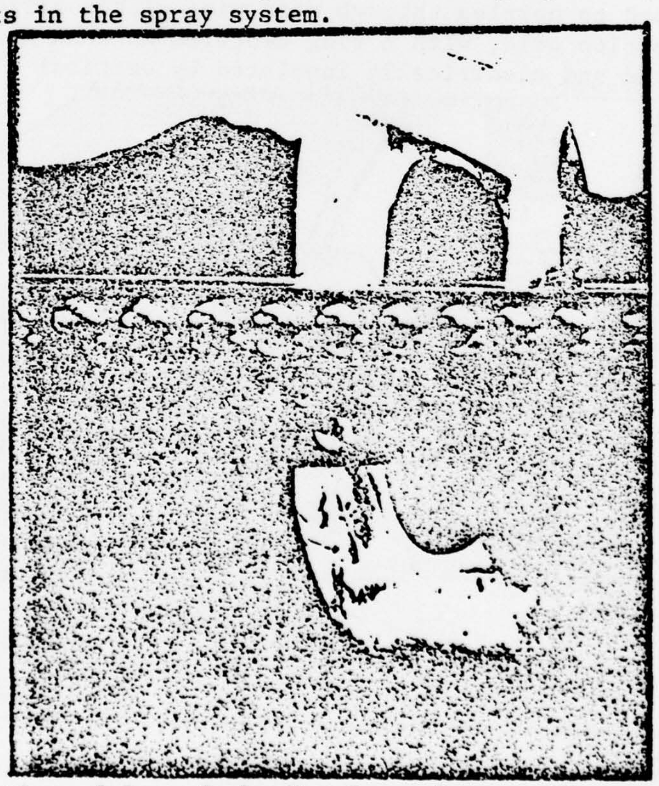

FIGURE 10. Section of One of the New Spray Booms. The nozzles, the charge-inducing grid, and an insulator grid support-insulator are shown.

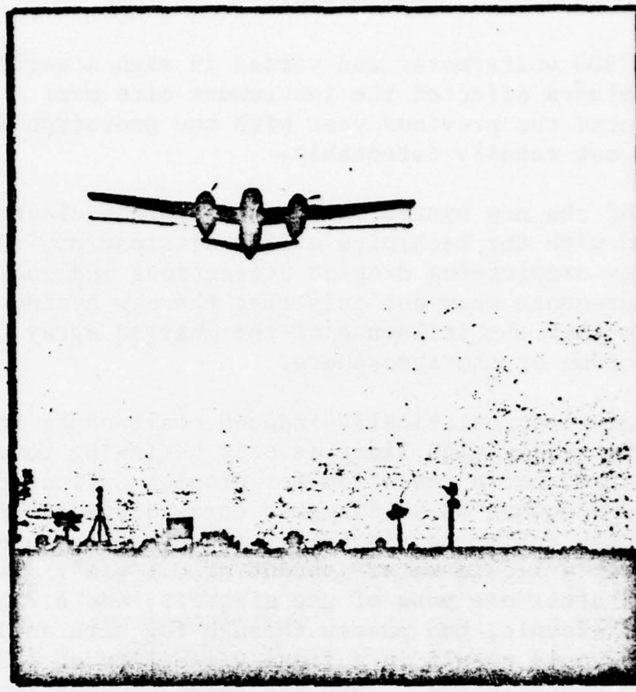

FIGURE 11. Clear-Air Tests to Demonstrate and Measure Spray-Charging Capability of the Electrostatic System.

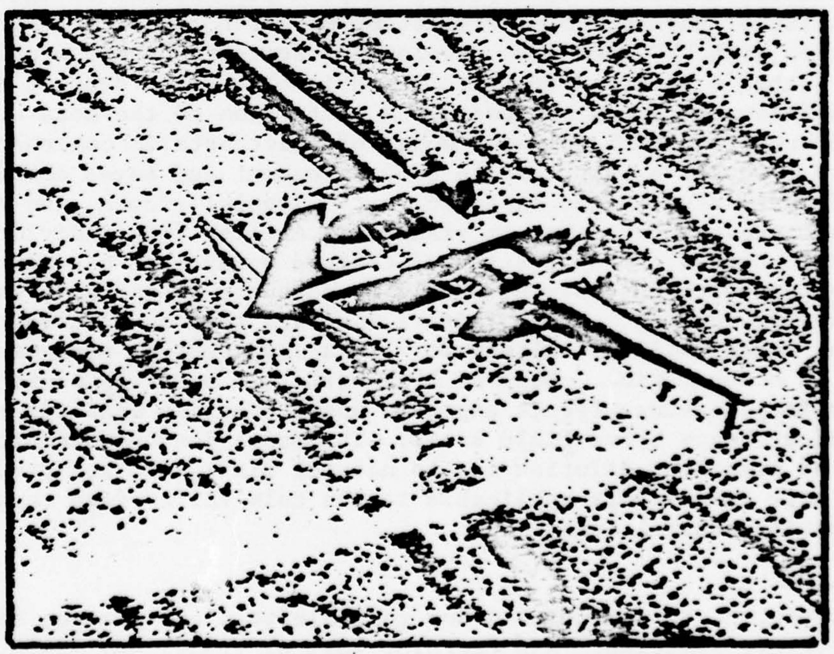

FIGURE 12. Clear-Air Test of the Electrostatic Fog Dispersal System.

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250 to more than 2300 volts/meter and varied in sign according to which of the two spray plumes affected the instrument site most strongly. In field tests conducted the previous year with the prototype system, induced fields were not readily detectable.

The effects of the new system on the atmospheric electric field are not to be confused with the mechanism of fog dissipation, which involves electrostatic spray droplet-fog droplet attractions and coalescence. However, the measurements show not only that the new system is operating properly, but also that the influence of the charged spray can carry through a large volume of the atmosphere.

Good theory of electrostatically-induced coalescence involving droplets charged below the Rayleigh limit is only beginning to emerge. However, assuming that Cochet's[3] equation for droplet collection efficiency is applicable, and assuming 80 μm diameter spray drops and 10 μm fog droplets, Carroz[4] has estimated visibility improvements through a fog depth of 150 ft with a liquid water content of 0.1 g/m^3. These amount to a factor of 1.2 after one pass of the aircraft, and 6.7 after ten passes. Thus, for example, ten passes through fog with an initial visibility of 0.2 mile could result in a final visibility of 1.3 miles. These estimates are very conservative. They are based on equations that model continuous growth of single droplets. It is well recognized that droplet growth simulated by this type of model is much too slow, because the stochastic nature of interacting droplet populations is ignored. Mr. Paul Tag of Environmental Prediction Research Facility (EPRF) in cooperation with NWC, has just developed a semi-stochastic droplet growth model. Cochet's equation for electrostatic effects on droplet coalescence is incorporated in the model. A comparison to the more accurate but more cumberson NCAR computer model of electrostatic coalescence showed that Cochet's method is in good agreement and saves computer time. The EPRF model reveals the expected faster droplet growth, and it predicts much greater increases in visibility arising from individual passes of the B-26 system. Thus dosages of charged spray that can now be applied with one pass with this system should be adequate to induce significant visibility improvements. All factors indicate that an electrostatic fog dispersal system will definitely work if a large enough area can be treated in a short time. Work at EPRF with this model is continuing so as to define clearing effects expected under specific conditions encountered at Foggy Cloud field sites. The model does not incorporate effects of treatment dilution due to natural mixing, so its predictions will be more immediately applicable to the calm Valley fogs than to the advecting coastal fogs.

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[3]Cochet, R. "L'evolution d'une gouttelette d'eau chargee dans un range à' temperature positive," ANN GEOPHYS, Vol. 8, (1952) pp. 33-54.

[4]Carroz, J. W., P. St.-Amand, and D. R. Cruise. "The Use of Highly Charged Hygroscopic Drops for Fog Dispersal." J WEA MOD, Vol. 4 (1972), pp. 54-69.

Spray droplets from the electrostatic system are estimated to have a mass-median diameter of approximately 80 μm. The charged droplets that most effectively strike a balance between occurrence in sufficient numbers and sufficient fallspeed will average roughly 40 to 70 μm in diameter during growth and fallout. Desirably, the effect of the spray treatment should be observed within about 30 minutes or less. Thus, experimental plans called for seeding primarily between 500 and 700 ft AGL, as dictated by droplet fallspeeds. Treating a given fog volume at successively lower altitudes may also be a desirable approach.

The first in-cloud check-out of the electrostatic system was conducted near China Lake in a low stratus deck approximately 100-ft thick The aircraft flew below cloud top. A distinct cut out of the lower part of the stratus was observed from the ground. This cut appeared about five minutes after seeding and clearly represented the swath of the aircraft. Beyond this, the test demonstrated that the system operates consistently in the wet environment of clouds, without such malfunctions as those due to arcing.

Proving the engineering aspects of the spray system was a major objective. In summary, the airworthiness, the spraying and charging capabilities, and a resistance to malfunction in the wet, cloudy environment were achieved. The instrument package in the B-26 directly monitoring the flow and charging parameters has been completely designed and construction is partially completed. The first flights with the system were conducted on 5 February, after much of the normal fog season had passed. This year the season ended early so no in-fog tests were possible at Visalia prior to scheduled disestablishment of the field site.

Two airborne fog and stratus dispersal tests were conducted off the California coast north of San Diego. No surface support with instrumentation or observers was possible in these cases, so visual evaluations were made from the Cessna 337 observation aircraft. On 13 February, a double layer of weak coastal stratus was seeded. The stratus definitely became more diffuse and mottled after seeding, and a corresponding downwind area over the beach cleared at the anticipated time. However, irregularities in the stratus adjacent to the seeding area also occurred and precluded drawing definite conclusions on the effectiveness of the treatment.

Coastal fog 800-ft deep with winds occurred on 28 February. Charged spray was dispensed over an orbital flight pattern. The fog tops were uneven; the B-26 flew low enough to stay below the lower tops most of the time. This unfortunately precluded good observations from on top. Clearing at levels within the fog could not be detected on flight passes through the treated area. Possibly, an orbital flight path is unsatisfactory for fog clearing. This will be investigated in future tests.

NPGS ION GENERATOR

As a follow-on to basic laboratory experiments, Dr. Gordon Schacher of the Naval Postgraduate School (NPGS) developed a field prototype ion generator for dispersing fog. The principle of operation is as follows: a high voltage is applied to a wire probe to produce an electrical breakdown (arcing) to the atmosphere; the arc thus generated ionizes the air; the highly mobile ions attach and give net charges to fog droplets which in turn coalesce by electrostatic attraction. This effect has been demonstrated in small-scale laboratory experiments.

A mobile 50-ft mast (Figure 13) with a grid-wire probe at the top (Figure 14) was assembled for the field tests. A single straight-wire probe was also used. Tests at Visalia in clear air demonstrated that a high rate of ion generation was possible with this equipment. Strong induced fields measured in clear air could not be detected during fog, thus suggesting that the fog was absorbing the charge between the probe on the mast and the measuring electrometer, and that, possibly, oppositely charge fog droplets were quickly neutralizing the charge by coalescing.

Induced changes in the visibility and droplet size distribution in the fog were not detectable. This is undoubtedly due partly to the ineffective targeting toward the recording instrumentation; the clear-air tests demonstrated that targeting from a point source is very difficult, even in low-wind conditions. Treating the fog at proper upwind distances from the target is also difficult when a ground-based point source is used, because of uncertainties in the times required for droplet growth and fallout.

Further investigation of this system would best be pursued in a cloud chamber of very large volume (more than 1,000 cubic meters), or with multiple ion sources in the field.

STRATUS GENERATION

The generation of stratus to suppress fog may be feasible. Stratus cloud decks absorb terrestrial infrared radiation. Part of this radiation is re-emitted to the subcloud layer and the earth. Thus a stratus deck prevents the escape of the "window" infrared radiation to space by trapping it. The return of trapped energy inhibits cooling of the air near the ground and, if sufficient, prevents or at least delays formation of fog. This natural effect of cloud layers on exchange of radiation may be utilized by generating stratus artificially.

Suitable moist, clear layers of the atmosphere can be seeded to generate fog droplets by using hygroscopic particles that serve as cloud condensation nuclei (CCN).

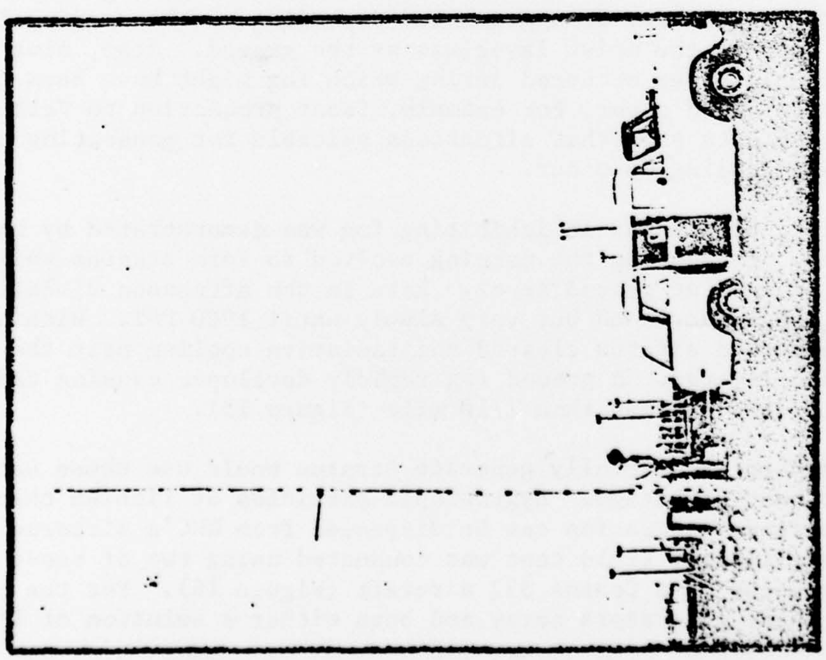

FIGURE 13. Mobile Ion Generator. Ions are distributed to surrounding fog from a wire probe at the top of the mast.

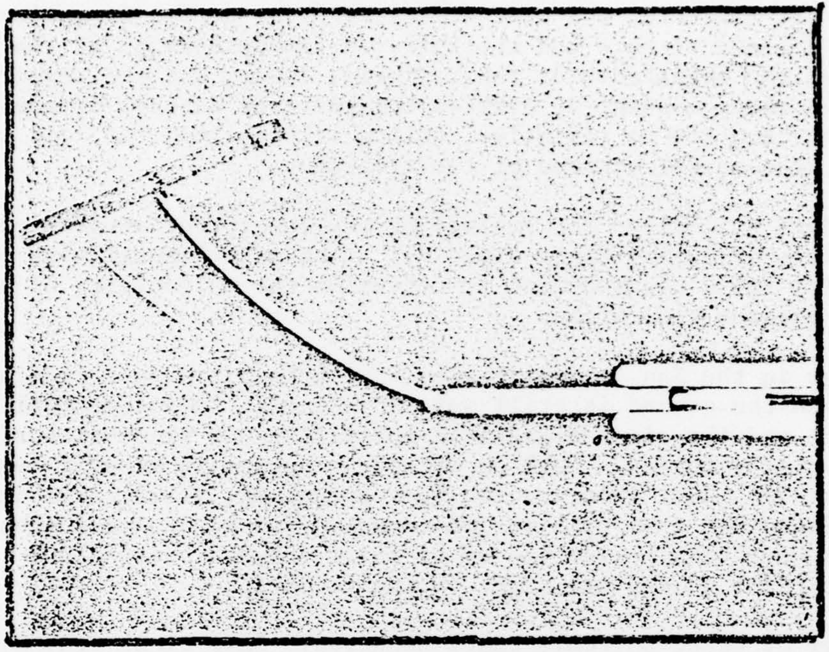

FIGURE 14. Grid-Wire Probe on the Mast of the Ion Generator.

Numerous questions regarding stratus creation need to be answered by experiment and observation. These questions pertain to the atmospheric thermal, moisture, and wind structure prior to fog formation; the presence or absence of haze and the infrared transmissivity of the air at this time; the magnitudes of the radiative losses and the required thickness and water content of created stratus; the natural deepening of created stratus due to radiative cooling at the cloud top; and the density and area-scale required of the treatment.

Basic data collection for evaluating the concept of stratus generation was initiated during Foggy Cloud VII. The experimental work included regular field observations to determine the suitability of conditions for stratus generation.

New fogs in the San Joaquin Valley form primarily after frontal passages, when the ground is still wet, substantial radiative cooling has occurred, and the air has regained sufficient CCN since cleansing by the frontal precipitation. Such an episode occurred in Visalia between 4-6 December 1974, just prior to the fog development illustrated in Figure 2. Soundings from this period revealed low winds and a clear, stable atmosphere with humidities of at least 75%-80% below 2,000 ft MSL on the night prior to and the night of fog formation.

A number of other suitable cases occurred. Only clear weather regimes with humidities of at least 75% and winds under 5 knots within some layer(s) between the surface and 5,000 ft above the ground were regarded as suitable. There were seven occurrences of conditions proper for generating stratus. There were seven other cases during which either stratus or fog might have been generated depending on the seeding level, because the base of the moist layer was at the ground. Also, nine additional suitable cases occurred during which fog might have been generated to provide cloud cover, for example, frost protection to Valley agriculture. These data show that situations suitable for generating stratus and inhibiting cooling do occur.

The effect of stratus in inhibiting fog was demonstrated by nature on 7 December. Fog during the morning evolved to form stratus while a dense haze remained at ground level. Late in the afternoon visibility under the stratus decreased but very slowly until 1900 PST. Within the next 45 minutes the stratus cleared and radiative cooling near the ground was accelerated. A ground fog rapidly developed causing the visibility to drop to less than 1/10 mile (Figure 15).

An effort to artificially generate stratus would use these natural processes to best advantage. Hygroscopic particles of lithium chloride (LiCl) for stratus generation can be dispensed from NWC's airborne jet seeder. A preliminary field test was conducted using two of these CCN generators mounted on a Cessna 337 aircraft (Figure 16). For the present application these generators spray and burn either a solution of lithium

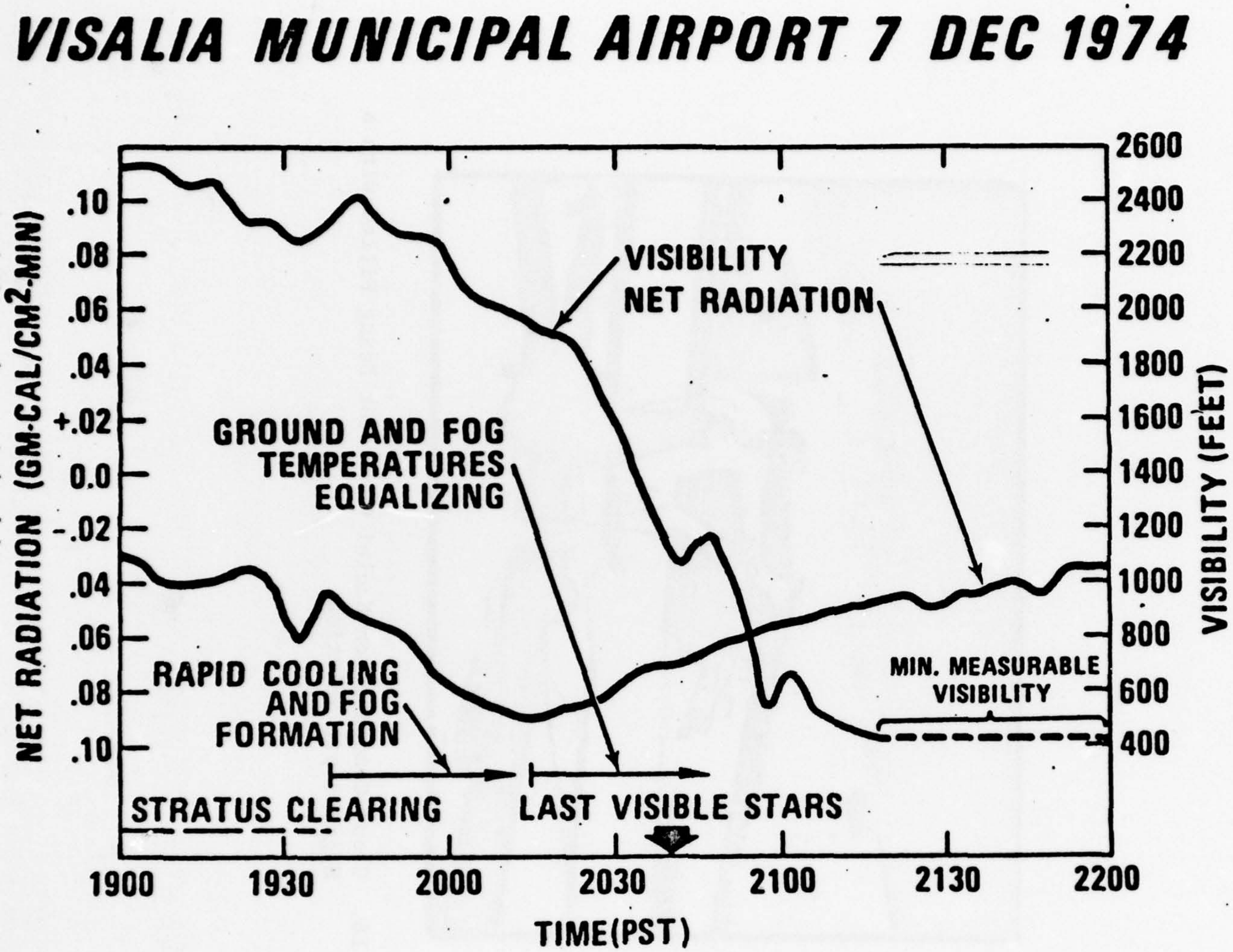

FIGURE 15. The Effect of Stratus in Inhibiting Fog Formation, as Demonstrated by Nature.

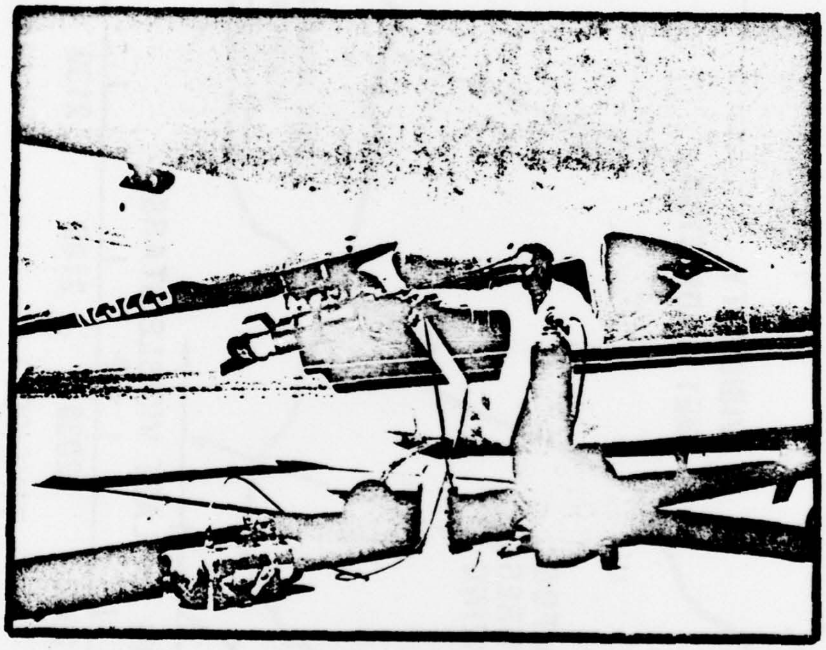

FIGURE 16. Cloud Condensation Nuclei Generator Being Filled with a Hygroscopic Solution.

perchlorate trihydrate ($LiClO_4 \cdot 3H_2O$) in acetone, or a solution of lithium chloride in acetone and methanol. The capacity of each seeder is seven gallons and the burn rate is 6 gal/hr with the selected nozzles. Approximately 10-15 lbs of LiCl can be dispensed over a period of approximately 1-2 hours during each test over a preselected area.

The heat from burning lithium perchlorate solutions is sufficient to cause molecular decomposition and vaporization of the $LiClO_4 \cdot 3H_2O$. The molecules recombine to form the LiCl particles which serve as CCN. The decomposition-recombination process yields small particles (diameter < 0.1 μm), which may be the most effective selection when the atmosphere has been cleansed by rain preceding a fog regime.

Burning lithium choride solutions does not decompose the LiCl molecules. The acetone burns and evaporates from each drop of spray, probably causing some drops to rupture, thus leaving particles roughly an order of magnitude larger (estimated mode diameter $\simeq 1.0$ μm). The LiCl solutions are much more viscous than the $LiClO_4 \cdot 3H_2O$ solutions. This increase in viscosity causes the spray drop sizes to increase rapidly. These properties of size and viscosity result in fewer CCN than from $LiClO_4 \cdot 3H_2O$ solutions but the larger particles are more likely to generate droplets of significant size, particularly when a natural haze is already present.

Water vapor from combustion of the solutions and from the aircraft exhaust contribute, along with atmospheric water vapor, to the generation of stratus.

The 75% relative humidity value used in isolating the data discussed above is apparently an appropriate practical threshold for droplet nucleation on the LiCl particles. Clouds were created with LiCl seeding during Project Foggy Cloud V.[5] Stratus was not generated during either of two test flights at Visalia. The humidity of about 65% at the seeding altitude (approximately 500 ft AGL) was apparently too low. Thus the problem of generating stratus appears to be mainly one of isolating proper weather conditions and determining adequate dosages of seeding material.

FOG STUDY WITH A MANNED HOT-AIR BALLOON

With the contract from the Office of Naval Research, NWC has instrumented a manned hot-air balloon for basic fog studies. Some of the specific objectives are to measure the rates of deepening of fog layers and changes in correlated parameters, to determine CCN concentrations, compositions and sizes in layer into which the fog is vertically propagating,

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[5]Naval Weapons Center. Project Foggy Cloud V, Panama Canal Warm Fog Dispersal Program, by R. S. Clark, et. al. China Lake, Calif. NWC, December 1973. 92 pp. (NWC TP 5542.)

to obtain profiles of fog liquid water contents and temperature structure, and to measure the penetration of solar radiation into fog.

The aerosol instrumentation includes a Mee Industries CCN counter, a Lundgren particle impactor, a centrifuge to sample fog water in bulk, and a cotton filter device to measure fog liquid water content. Temperature, dew point, hemispherical solar radiation, and net radiation in the 0.3-80 µm range are monitored with Weather Measure equipment. Photography and visual observations complement the system.

The instrumentation is carried on a pallet suspended 12 ft below the gondola to minimize heat effects from the balloon (Figures 17 and 18). The balloon is operated on a 2,000-ft tether from a winch truck. Power is provided from the ground via a 2,000-ft cable. The entire package, including the pallet, cable and tether, weighs about 400 lbs. This weight allows a margin of about 300 lbs in the balloon's lifting capability. The balloon is raised and lowered as necessary to follow fog top or to sample along profiles through the fog. Details have been presented by Reinking.[6]

The principal effort this year was devoted to constructing and testing the instrument package. Data-gathering test flights through and above fog were made on two occasions. Analyses of the performance of the instrument system and the physical significance of the data are underway.

Preliminary analyses of observations and measurements made with the balloon reveal that heat effects are negligible below the gondola. The data reveal the temperature structure of the atmosphere and the positions of fog tops relative to capping inversions in greater detail than is possible with radiosonde monitoring. The fogs extend upward well into observed inversions, rather than topping-out where the temperature begins to increase as has normally been assumed. Liquid water contents were found to be quite uniform throughout the depths of the observed fogs.

INSTRUMENTATION FOR MONITORING FOG MODIFICATION AND MICROPHYSICS

The instrumentation system for this project is designed to control seeding and observation aircraft, to monitor the seeding inputs, and to measure the physical system of parameters representing the fog regime. The whole system is outlined in Table 1 in terms of measured parameters, the purpose for monitoring each, and the instrumentation. The instrument site (Figure 19) included a meteorological van, 50-ft tower, GMD rawinsonde unit, radars, and a system of the individual instruments. Some key instruments are shown in Figures 20 and 21.

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[6] Reinking, R.F. "Manned Hot-Air Balloons as Warm Fog Research Vehicles," in Proceedings of the 8th AFCRL Sci. Balloon Symposium, 30 Sep.-3 Oct. 1974, Hyannis, Mass., 1974. Pp. 552-566. (AFCRL-TR-74-0393.)

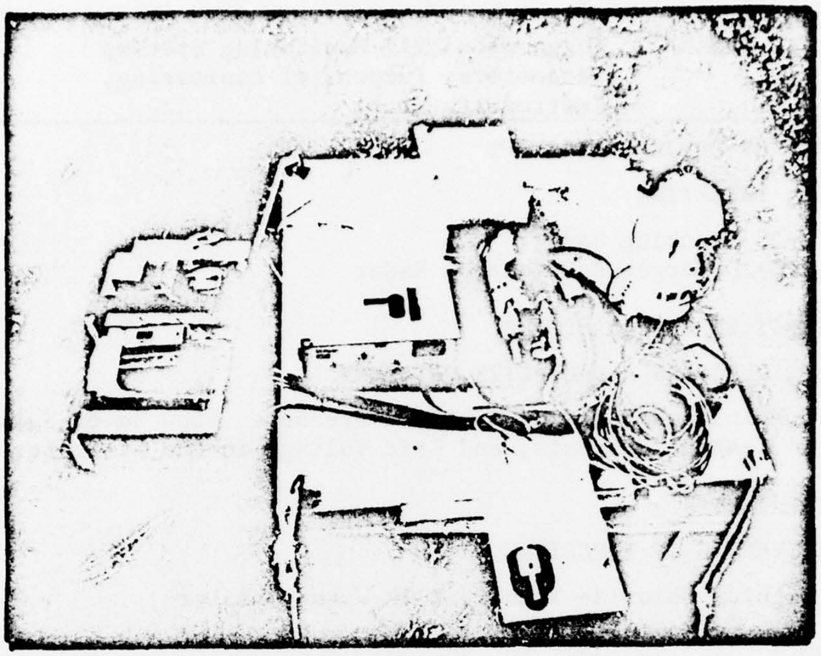

FIGURE 17. Instrumented Pallet That is Suspended From a Manned Hot-Air Balloon for Fog Studies.

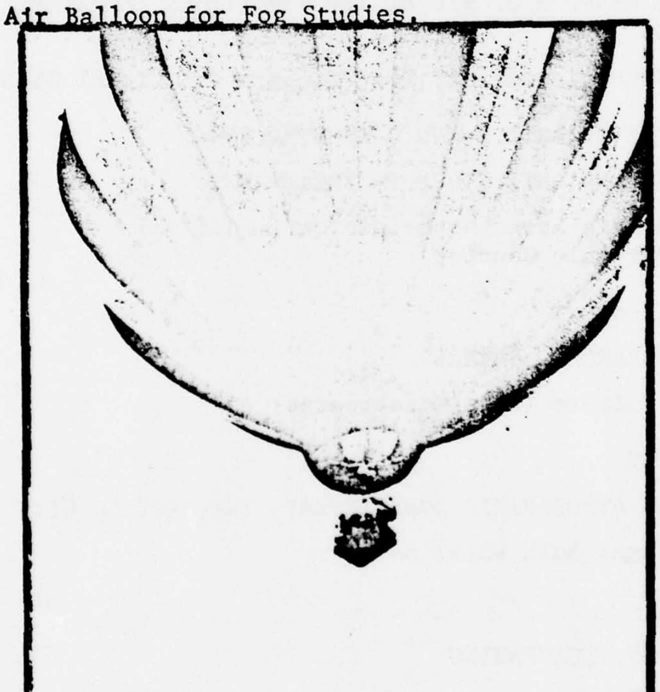

FIGURE 18. Hot-Air Balloon With Instrumented Pallet.

TABLE 1. Foggy Cloud VII Monitoring Systems (Parameters, Purpose of Monitoring, Instrumentation)

FLIGHT PATHS OF PROJECT AIRCRAFT

SAFETY, TARGETING

M-33 Tracking Radar
TPS-1D Target Acquisition Radar

B-26 TREATMENT SPRAY PARAMETERS

AMOUNT, DURATION AND QUALITY OF SPRAY

Specialized Metering of Fluid Pressure, Flow Rate, Spray and Leakage Currents, and Grid Voltage in the Aircraft.

PLUME OF TREATMENT

EFFECTIVENESS OF TARGETING

Lithium Chloride Tracer, Bulk Water Sampler

VISIBILITY

QUANTITATIVE MEASURE OF VISIBILITY VARIATIONS IN NATURAL AND TREATED FOG

Laser Transmissometer; Two Videographs; Visual Observations

FOG DROPLET SIZE DISTRIBUTION AND CONCENTRATIONS

NATURAL CASE, AND SHIFTS DUE TO TREATMENTS

A. D. Little Laser Nephelometer (modified)
Royco Particle Counter

FOG LIQUID WATER CONTENT

MAGNITUDES, CHANGES, TRENDS

Cotton Filters (Mass Measurement)

FOG WATER CHEMISTRY

BASIC DATA ON ATMOSPHERIC CONSTITUENTS INTERACTING WITH FOG

Centrifugal Bulk Water Sampler

PARTICULATES, CCN

FOG NUCLEATION, SCAVENGING

Mee CCN Counter
Lundgren Impactor for size and chemical composition

TABLE 1. (continued)

ATMOSPHERIC ELECTRIC FIELD

- TARGETING AND TIME-DURABILITY OF SPRAY CHARGES, AND INTERACTION OF SUCCESSIVE SPRAYS
  - Kiethly Electrometers

RADIATION BUDGET

- SOLAR AND TERRESTRIAL RADIATION INTERACTIONS WITH STRATUS AND FOG
  - Net Radiometer (0.3 - 80 μm)
  - Solar Hemispherical Pyranometer (0.3 - 3 μm)

TEMPERATURE AND DEW POINT

- INDICATE BUILDUP, PERSISTENCE AND DECAY OF FOG: RADIATIVE EFFECTS
  - Weather Measure Thermistors and LiCl Hygrometers (25 and 50' AGL)
  - Hewlett-Packard Quartz Thermometer/Wet Bulb

BAROMETRIC PRESSURE

- BASIC; RATE OF CHANGE PERTINENT TO FORECASTING POST-FRONTAL FOG
  - Aneroid Recording Barometer

LOW LEVEL WINDS

- ADVECTION, TARGETING, MIXING
  - Weather Measure Anemometers and Vanes (25 and 50' AGL)

UPPER AIR PROPERTIES

- THERMAL AND MOISTURE STRUCTURE, WINDS FOR TARGETING
  - GMD Unit, Rawinsondes

COMMUNICATIONS

- AIR-TO-AIR, AIR-TO-GROUND, GROUND-TO-GROUND COORDINATION
  - Bendix Transceivers

TIMING

- COORDINATION
  - WWV Receivers

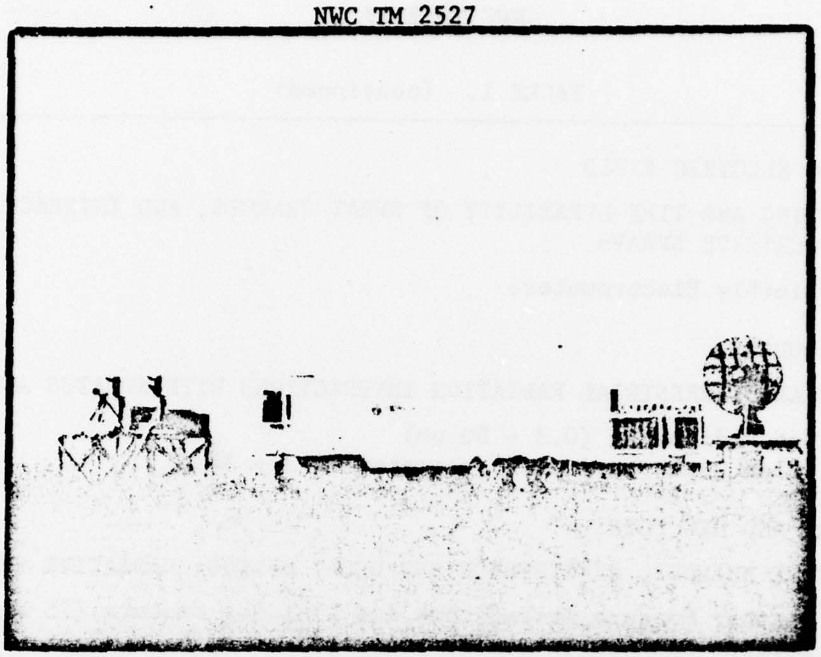

FIGURE 19. Instrumented Field Site for Foggy Cloud VII. The meteorological van, GMD van, instrument platform, and the instrumented tower in the background in the fog are shown.

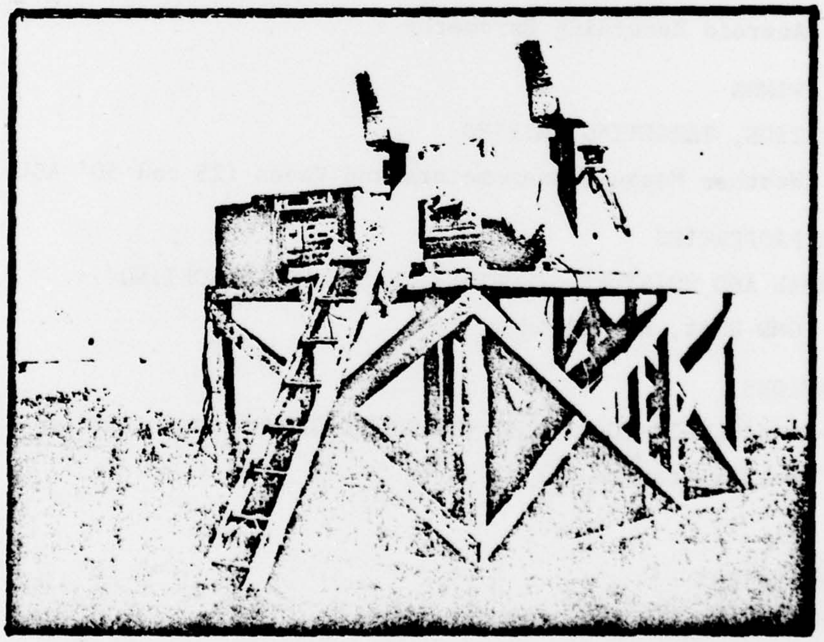

FIGURE 20. Instrumentation Platform. Shown are videographs and laser transmissometer for measuring visibility; Royco particle counter and laser nephelometer for sizing and counting fog droplets.

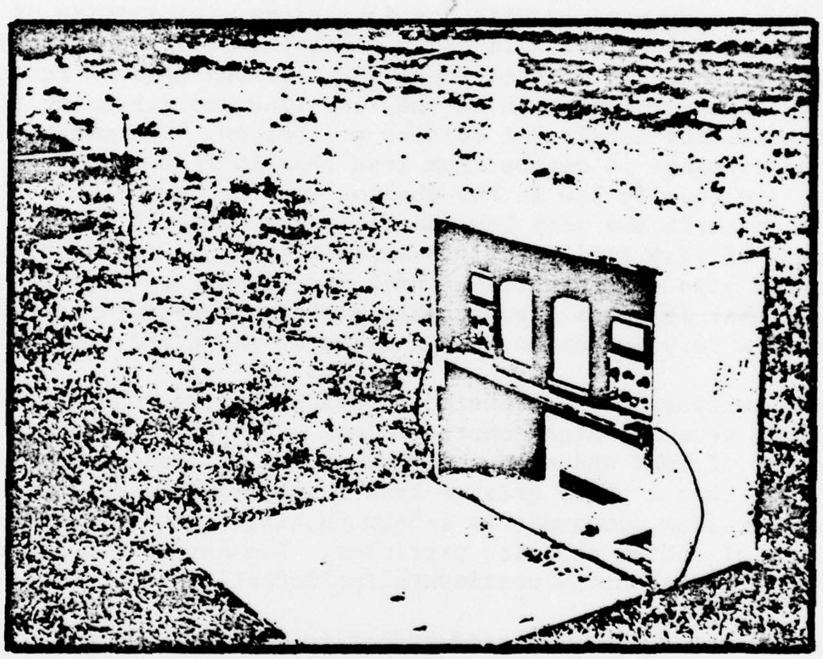

FIGURE 21. Kiethly Electric Field Meters.

The best approach to evaluating treatment effects of fog dispersal and stratus generation tests was determined to be that of directly measuring changes in interrelated parameters. The tests are not randomized and statistical evaluations are minimized.

Effects occur in two classes, obvious and subtle. The latter must be correlated with treatments by proving repeatability.

Some analyses of the data gathered with the instrument system have been presented in previous sections of this paper. Other analyses of the clear-air test data and the fog microphysics are proceeding. Some pertinent preliminary results are as follows: near-calm conditions are indeed prevalent during Valley fogs; visibilities in the Valley fogs drop to minimums very rapidly with fog formation; visibilities of 100-300 ft are common and persistent; and visibilities are considerably lower and less variable than in coastal fogs. Regular and special rawinsondes provided significant information on the formation and deepening of fog and the potential for artificial stratus generation. The natural fogs were observed to range in depths from less than 10 ft to about 4,000 ft. Visibilities are equally low in the shallow and the deep fogs. The fog liquid water contents are very low (normally well under $0.1 g/m^3$); high concentrations of very small droplets explain the low visibilities. Data on droplet size distributions, which are subject to further calibration, suggest that 15 μm is a reasonable practical upper limit to droplet diameter. A very approximate mean diameter is of the order of 6 μm.

Chemical analyses of atmospheric constituents from one pre-fog/new-fog episode reveal: high concentrations of particles under 0.5-μm radius composed of lead and sulfur compounds and of iron compounds in sizes from less than 1 μm to greater than 5 μm; moderate concentrations of calcium and potassium compounds as 1-5-μm particles; and undetectable concentrations of sodium chloride particles. The aerosols that occurred in this case were distinctly continental/pollutant types.

During a second case with good radiative cooling and calm winds, predicted fog failed to form. In this case, moderate concentrations of sodium chloride particles exceeding 1-μm radius were found. Compared to the first case, very significantly lower concentrations of particles composed of sulfur, lead, iron, potassium, and calcium compounds occurred. A marine influence is suggested. These analyses support the premise that aerosols in the Valley must build up to a significant level before fog will form.

FUTURE FIELD TESTING AND MEASUREMENT

Project Foggy Cloud VIII is planned for FY 1976. The major emphasis will be placed on field-testing the new electrostatic fog dispersal system. The system is now mechanically and electrically operational, except for the system-monitoring data package. The minor engineering and fabrication necessary to finish this system will be completed. The B-26 aircraft is somewhat limited in its ability to climb well with the load of the current system. A larger R5D (C-54) aircraft is available and under consideration. The R5D would better serve the present application and also would allow for fabrication of a follow-on system with longer, higher-volume spray booms.

Plans also include actual clear-air seeding to test the stratus generation technique of preventing fog. The ground-based and balloon-borne instrument systems for monitoring physical and microphysical fog properties provided extremely useful data. These studies will continue in support of fog dispersal and fog forecasting efforts.

The coming tests and measurement program will be conducted at coastal and/or valley sites as appropriate. Some of the meteorological and microphysical factors pertaining to the site choice are presented in Table 2. Factors that represent advantages and disadvantages for the experimental stages of testing are indicated. DOD ship and aircraft operations are significantly affected by the coastal marine fogs, and eight DOD airfields are affected by the San Joaquin/Sacramento Valley fogs.

TABLE 2. A comparison of Factors Pertaining to Fog Dispersal Testing in California Coastal and Valley Fogs*

Coastal Fog	Valley Fog
(-) Advection fog; often significant mixing; targeting of treatments and dilution of effects are problems.	(+) Radiation fog; light-to-calm winds.
(-) Visibilities relatively variable; sorting treatment effects from natural variations can be difficult.	(+) Visibilities consistent and generally lower than in coastal advection fog
(-) Dissipation in early AM common; sometimes difficult to sort natural from induced dissipation during preferred daylight testing.	(+) Fog normally persists until 1100 local time or later, sometimes persists for days.
(±)**Fog droplet diameters of the order of 1.0-40-µm; moderate induced coalescence rate expected.	(+)**Fog droplet diameters of the order of 1-15 µm; rapid induced coalescence rate expected.
(+) Fog rarely less than 200-ft deep and commonly of preferred 300-1,000-ft.	(-) Fog occasionally too shallow for good testing (but deep fog is also common).
(+) High frequency of new fogs, new testing opportunities.	(-) Lesser frequency of new fogs, common evolution to stratus clouds which present poor opportunity for instrumented or visual observations.
(+) Stratus with clear, definite bases common; suitable for sub-cloud visual evaluation of tests.	(-) Stratus bases cannot be readily separated visually from haze below.

*Factors considered advantageous (+) and disadvantageous (-) to experimental testing are indicated.

**Some advantage in treating fogs with smaller droplets may exist, assuming the new EPRF model is correct; this result is contrary to previous assessments.